Case Docket: TWI-010

POLISHING PADS AND MANUFACTURING METHODS

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CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims benefit of provisional United States patent application Docket Number TWI-004, filed on 29 October 2001, entitled "POLISHING PADS AND MANUFACTURING METHODS." This application is related to provisional United States patent application Docket Number TWI-002, filed on 29 October 2001, entitled "PADS FOR CMP AND POLISHING SUBSTRATES" and United States patent application Docket Number TWI-010, filed on 11 December 2001, entitled "PADS FOR CMP AND POLISHING SUBSTRATES." The contents of all of these applications are incorporated herein by this reference in their entirety.

TECHNICAL FIELD

This invention relates to polymer materials and methods of making the polymer materials for applications such as chemical mechanical planarization (CMP) and polishing of substrates such as semiconductor substrates, wafers, metallurgical samples, memory disk surfaces, optical components, lenses, and wafer masks. More particularly, the present invention relates to CMP pads and pads for polishing and methods of manufacturing pads having improved properties.

BACKGROUND

Processes employing CMP or polishing techniques have been widely used to planarize the surface of wafers during the various stages of device fabrication in order to

improve yield, performance, and reliability of the fabrication process. In fact, CMP has become essentially indispensable for the fabrication of advanced integrated circuits.

Integrated circuits are chemically and physically integrated into a substrate by patterning regions in the substrate and layers on the substrate. To achieve high yields, it is usually necessary to recreate a substantially flat substrate after processing steps that leave topographic features on the surface of the wafer, features such as surface irregularities, bumps, troughs, and trenches.

Various types of pads have been developed in efforts to meet the needs of CMP processes and polishing processes. For a more detailed discussion of representative types of pads see PCT application W096/15887, the specification of which is incorporated herein by reference. Other representative examples of pads and methods of their fabrication are described in U.S. patents 4,511,605, 4,708,891, 4,728,552, 4,841,680, 4,927,432, 5,533,923, 6,126,532, 6,231,434, and 6,287,185, the specifications of which are also each incorporated herein in their entirety by this reference.

Although CMP pads and polishing pads are in extensive use, a need remains for improved pads, which provide efficient planarization across electronic device substrates and have improved polishing efficiency and longer pad life for higher production efficiency. In addition, there is also a need for pads that are harder and denser than the standard technology pads while maintaining satisfactory porosity. Furthermore, there is a need for improvements in the manufacturing processes for pads.

SUMMARY

This invention pertains to improved polymer materials such as materials for pads for planarizing or polishing substrates such as pads for CMP and methods of manufacturing the materials. The present invention seeks to overcome one or more of the deficiencies of the properties of the materials and provides methods for manufacturing the materials.

An aspect of the present invention is a method of manufacturing polymer materials having properties that are determined by selected process conditions. The properties can be modified for a variety of applications. An exemplary application is a material for pads for planarizing a substrate. One embodiment of the method includes the steps of providing a polymer sheet having a substrate contacting area, heating the area a sufficient amount, and

applying mechanical pressure greater than 1500 psi (10.3 megapascals) to the area during at least a portion of the heating step. As an option, this embodiment may further include the steps of cooling the polymer sheet, and providing a sufficient amount of mechanical pressure to the sheet during at least part of the cooling step so that the area is substantially planar. As another option, the pressure during the heating step may be applied so that the sheet is compressed to a predetermined thickness that is less than the maximum compression for the selected pressure.

In another embodiment, the method includes the step of providing a polymer sheet that has a non-woven felt impregnated with a thermoplastic polymer. The sheet has a density less than about 0.7 grams per cubic centimeter, and the sheet has a substrate contacting area. The method further includes the steps of heating the area a sufficient amount and contemporaneously applying a sufficient amount of mechanical pressure so that the density of the sheet increases to greater than about 0.75 grams per cubic centimeter.

Another aspect of the present invention is a polymer composite comprising a non-woven felt of polymer fibers impregnated with a resin. The composite has a density greater than about 0.70 grams per cubic centimeter. In addition, the composite has a Shore D hardness of at least 60.

Another aspect of the present invention includes electronic devices for which the fabrication process includes at least one planarization step performed using a pad according to embodiments of the present invention.

It is to be understood that the invention is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. In addition, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

As such, those skilled in the art will appreciate that the conception, upon which this disclosure is based, may readily be utilized as a basis for the designing of other structures, methods and systems for carrying out aspects of the present invention. It is important, therefore, that the claims be regarded as including such equivalent constructions insofar as they do not depart from the spirit and scope of the present invention.

It is to be noted that the abstract is not intended to define the invention of the application nor is the abstract intended to be limiting as to the scope of the invention in any way. In other words, the invention is to be measured by the claims.

The above and still further features and advantages of the present invention will become apparent upon consideration of the following detailed descriptions of specific embodiments thereof.

DESCRIPTION

Embodiments of the present invention will be discussed below, primarily, in the context of materials and processes for chemical mechanical planarization such as those used for fabricating integrated circuits. However, it is to be understood that embodiments in accordance with the present invention may be used for other applications such as polishing substrates.

One embodiment of the present invention is a method of manufacturing a polymer sheet for a pad for CMP processes. The method includes the steps of providing a polymer sheet having a substrate contacting area, heating the area a sufficient amount, and applying sufficient mechanical pressure to the area during at least a portion of the heating step. As an option, this embodiment may further include the steps of cooling the polymer sheet, and providing a sufficient amount of mechanical pressure to the sheet during at least part of the cooling step so that the area maintains planarity after completion of the processing. As another option, the pressure during the heating step may be applied so that the sheet is compressed to a predetermined thickness that is less than the maximum compression possible for the selected pressure.

Preferably, the method steps for embodiments of the present invention use conditions that substantially do not decompose the material being processed. Generally, this will mean that the upper limit for applying heat will be determined by thermal decomposition characteristics of the polymer sheet. In other words, the temperature during heat application and the time at temperature are important.

In a preferred embodiment, the method includes the step of providing a polymer sheet that has a non-woven felt impregnated with a thermoplastic polymer. The sheet has a density less than about 0.7 grams per cubic centimeter, and the sheet has a substrate

contacting area. The method further includes the steps of heating the area a sufficient amount and contemporaneously applying a sufficient amount of mechanical pressure so that the density of the sheet increases to greater than about 0.7 grams per cubic centimeter.

Methods according to embodiments of the present invention are particularly advantageous for fabricating polishing pads from polymer sheets of non-woven felt impregnated with a thermoplastic resin. Because of the thermoplastic properties of the polymer sheets, the sheets can be compressed through applications of heat and pressure and remain at least partially compressed after removal of the heat and pressure. Preliminary experimental results indicate that some polyester felts impregnated with polyurethane have undergone about a fifty percent decrease in thickness upon application of sufficient heat and pressure.

The pads made from the compressed polymer sheets are more dense and therefore harder and stiffer. These improvements in the properties of the sheets improve the CMP characteristics of the pads. In other words, the sheets become more advantageous for CMP processes as a result of the heat and pressure treatments. For some applications, the resulting pad has higher planarization efficiency than standard felt pads. The higher efficiency occurs with substantially little or no loss of other performance properties of the pad.

Methods according to embodiments of the present invention can be used to convert the material used for relatively soft felt pads into materials that are as hard or harder than standard hard pads such as the polyurethane pads without felt. In addition, embodiments of the present invention can make the materials of relatively soft felt pads as dense or denser than the standard hard pads. Preliminary test results indicate that embodiments of the present invention can offer essentially all of the advantages of the hard pad and essentially all of the advantages of a soft pad.

The density of a pad, of course, is related to the porosity of the pad. A high-density is needed and preferable for some applications of CMP. For those applications, polishing pads according to some embodiments of the present invention have densities in the range of from about 0.5 grams per cubic centimeter to about 1.2 grams per cubic centimeter.

Embodiments of the present invention have been used to produce a pad having a density of about 1.03 grams per cubic centimeter. The pad was made from a starting

polymer sheet comprising a non-woven thermoplastic resin impregnated felt having a density of about 0.59 grams per cubic centimeter. During the process, the thickness of the sheet was decreased from an initial thickness of about 0.049 inches (1.24 mm) to a post-process thickness of about 0.027-0.028 inches (0.68-0.71 mm). The thickness decrease produced a substantially corresponding increase in the density of the polymer sheet. The hardness of the polymer sheet also increased. The pad fabricated from the sheet, after the heat and pressure processing, was more dense and harder than the starting polymer sheet.

In an embodiment of the present invention, a polymer sheet having a nonwoven felt, such as a polyester, impregnated with a thermoplastic resin, such as a polyurethane, was used as a starting polymer sheet. The starting polymer sheet had a Shore D hardness of about 50. The application of sufficient heat and pressure to the starting polymer sheet produced an increase in the hardness of the sheet to a Shore D hardness of about 60-62.

Some embodiments of the present invention have a Shore D hardness from about 50 to about 65 and all subranges subsumed therein. Preferably, pads made according to embodiments of the present invention have a Shore D hardness of at least about 60. Preferred embodiments have a Shore D hardness from about 60 to about 62 and all subranges subsumed therein.

A preferred embodiment of the present invention is a pad for CMP that includes polymer composite having a non-woven felt of polymer fibers impregnated with a resin. To produce the pad, the polymer composite is subjected to heat and pressure so that the composite has a density greater than about 0.70 grams per cubic centimeter. In addition, the composite has a Shore D hardness of at least 60.

Before applying the methods according to embodiments of the present invention to a polymer sheet, the sheet typically has a rebound, also referred to as compressibility, of 80 to 90 percent in response to applications of pressure. This property is retained for a range of temperatures. However, at temperatures above the temperatures for high rebound, the polymer sheet loses some of its rebound properties. In other words, after applications of pressure at temperatures above the temperatures for high rebound, the polymer sheet is less capable of returning to about its original dimensions, i.e. the dimensions before applications of pressure at the elevated temperatures. The temperatures where the polymer sheet exhibits

low rebound are defined here as temperatures for low rebound. When processed at temperatures for low rebound, the rebound is typically about 30 percent.

As indicated earlier, the process conditions for embodiments of the present invention will be determined in part by properties of the starting polymer sheet. The following example provides process conditions that have been used for embodiments of the present invention. In this example, the polymer sheet includes a nonwoven felt of polymer fibers such as, for example, polyester fibers or nylon fibers. The felt is impregnated with a resin such as, for example, a thermoplastic polyurethane. The polymer sheet has dimensions of about 10.5 inches x 10.5 inches and a thickness of about 0.05 inches. The polymer sheet is placed between two substantially smooth steel surfaces. The steel surfaces are heated to about the selected processing temperature. Suitable processing temperatures for this example are in the range of from about 300 degrees F (149 degree C) to about 450 degrees F (232 degree C), including all temperatures and ranges of temperatures subsumed therein. Preferred temperatures are in the range of about 375 degrees F (191 degree C) to about 400 degrees F (204 degrees C), including all temperatures and ranges of temperatures subsumed therein.

Preferably, though it may not be required, the polymer sheet is allowed to contact the heated surfaces for a period of time so that the temperature of the polymer sheet increases to about the temperature for processing. In other words, the sheet may be preheated before application of the high pressure. In this example, the polymer sheet was allowed to heat for about 20 seconds. After heating, pressure was applied to the polymer sheet via the steel surfaces. Suitable pressures for embodiments of the present invention are pressures greater than about 1500 psi (10.3 megapascals). Preferably, the pressures are greater than about 2500 psi (17.2 megapascals). Some particularly good results were obtained using a processing pressure of about 2900 psi (20 megapascals).

For some of the experiments, a pressure of about 2900 psi (20 megapascals) was applied for a period of about 10 seconds. For other experiments using a pressure of about 2900 psi (20 megapascals), the pressure was applied for a period of about 10 seconds followed by a 180-degree rotation within the plane of the sheet and then followed by another application of pressure at 2900 psi (20 megapascals) for a period of about 10 seconds. The two-step pressure application resulted in greater uniformity of properties of the polymer

sheet. It is to be understood that the equipment used for this experiment may not have been optimized for process uniformity and, therefore, should not be considered as a limitation for practicing the present invention.

Following the application of heat and pressure, the sheet was allowed to cool while sandwiched between two substantially flat plates of aluminum. The plates of aluminum were arranged to provide sufficient pressure to keep the polymer sheet substantially flat during at least part of the cooling step so as to prevent the formation of wrinkles or waves in the surface of the polymer sheet.

There are numerous methods of compressing the polymer sheet to a predetermined thickness. For the present example, physical stops having a thickness about equal to the predetermined thickness can be placed between the steel surfaces. The physical stops can be used to prevent the polymer sheet from being compressed more than the predetermined thickness.

A polymer sheet having a thickness of about 0.050 inches (1.3 mm) was heated to a temperature in the range of about 375 degrees F (191 degrees C) to about 400 degrees F (204 degrees C). Pressure was applied to the heated polymer sheet until the polymer sheet was compressed to a predetermined thickness fixed by a physical stop having a thickness of about 0.020 inches (0.51 mm). After removal of the pressure and the heat, the polymer sheet had a thickness of about 0.030 inches (0.76 mm). It is to be stood that the starting thickness of the polymer sheet for this example is for purposes of illustration. Other thicknesses can be used for the starting material thickness.

For the previous example, heated plates were used for carrying out the processing steps. As known by those skilled in the art, an alternative would be to use heated rollers for applying the heat and pressure. In addition, other known techniques for heating and applying pressure can be used in embodiments of the present invention.

Embodiments of the present invention can be used to produce pads having substantially selectable porosity and density profiles through the thickness of the pad. In other words, by selecting the processing conditions of temperature, pressure, and time duration of their application, the porosity profile near the surface of the pad may differ from that of the profile away from the surface at locations near the middle of the thickness of the pad, i.e., the midpoint of the pad thickness. Optionally, heat may be applied to both sides of

the starting polymer sheet or heat may be applied to only one side of the polymer sheet so as to achieve selectable density profiles through the thickness of the pad.

Table 1 summarizes the physical properties of some embodiments of polishing pads according to the present invention.

TABLE 1

Property	Suitable	Preferred
Pad Density gm/cc	0.5-1.2	about 1
Fiber to Polymer Resin Ratio		55:45
Hardness, Shore D	> about 50	60-62
Felt Density gm/cc		0.32

Embodiments of the present invention are especially advantageous for producing pads for applications where the substrate to be planarized initially has a highly nonplanar topography. These types of topographies are often encountered in oxide polishing processes for interlayer dielectric and intermetal dielectric fabrication steps for integrated circuits. Pads made according to embodiments of the present invention are particularly suitable for applications such as shallow trench isolation and oxide CMP. It is also potentially advantageous for polishing copper metallization and for applications involving deposition and etch.

Specifically, one embodiment of the present invention is a pad, prepared according to the present disclosure, for CMP of a substrate for the purpose of forming at least one of: shallow trench isolation structures, interlayer dielectric structures, intermetal dielectric structures, and copper metallization structures.

Polishing pads according to embodiments of the present invention are capable of providing satisfactory polishing results in addition to having operating lifetimes that are substantially longer than that for standard technology pads. Experiments have been conducted in which CMP pads made according to the present invention can be used to process about 1300-1400 wafers before needing to replace the pad. Whereas, comparable

processes using standard technology pads are only suitable for processing about 350 wafers. Clearly, use of embodiments of the present invention can provide pads having longer operation lifetimes.

Embodiments of the present invention also offer additional advantages for applications such as CMP. For example, with normal slurry consumption, pads according to embodiments of the present invention provide adequate removal rate, satisfactory non-uniformity, and enhanced planarization efficiency without a gross increase in defect production. In some instances, the planarization efficiency can be increased from about 70 percent to about 80 percent as a result of using pads according to embodiments of the present invention.

A wide range of polymer resins may be used in embodiments of the present invention. Suitable polymer resins include resins such as, for example, polyvinylchloride, polyvinylfluoride, nylons, fluorocarbons, polycarbonate, polyester, polyacrylate, polyether, polyethylene, polyamide, polyurethane, polystyrene, polypropylene, and mixtures thereof. In a preferred embodiment, the resin comprises a polyurethane.

An alternative embodiment of the present invention includes improving the CMP properties of existing CMP pads. For instance, pads such as the Model 813 CMP pads that are commercially available from Thomas West Incorporated have been further processed using method embodiments of the present invention to produce CMP pads having properties such as higher hardness, higher density, and higher stiffness than the Model 813 CMP pad. The additional processing of the Model 813 CMP pad produced an increase in the operating life of the pad compared to that of the standard Model 813 CMP pad.

In addition, thermosetting polymer sheets such as those used in products made by Rodel Incorporated may also be used to produce CMP pads having properties such as higher hardness, higher density, higher stiffness, and other properties desirable for improved CMP processing.

Polytex polymer sheets such as those comprising grown polyurethane tubes anchored to a base may also be processed according to embodiments of the present invention to produce CMP pads having properties such as higher hardness, higher density, higher stiffness, and other properties desirable for CMP processing.

Another embodiment of the present invention includes electronic devices for which the fabrication process includes at least one planarization step performed using a polishing pad according to embodiments of the present invention.

While there have been described and illustrated specific embodiments of the invention, it will be clear that variations in the details of the embodiments specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims and their legal equivalents.